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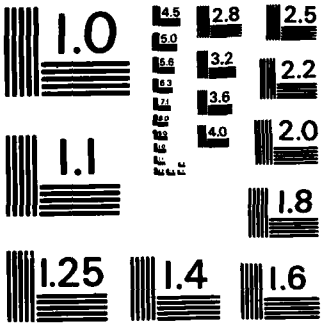

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RESULTS FROM A U.S. ABSOLUTE GRAVITY SURVEY

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Abstract. Using the recently completed JILA absolute gravity meter, we made a survey of twelve sites in the United States. Over a period of eight weeks, the instrument was driven a total distance of nearly 20,000 km to sites in California, New Mexico, Colorado, Wyoming, Maryland, and Massachusetts. The time spent in carrying out a measurement at a single location was typically one day. We report the results of the measurements in this survey along with earlier measurements made with the instrument, discuss the measurement accuracy, and compare our results with other measurements.

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1. Introduction

We have recently completed an absolute gravity survey at twelve sites in the U.S. (see Fig. 1). Eight ~~of the~~ sites had been previously occupied by other absolute instruments and four were new sites chosen because they were near locations in which other measurements relevant to the study of geodynamics were made.

The new instrument (see Fig. 2) — described elsewhere in detail [Zumberge et al., 1982; Faller et al., 1979] — consists of a freely-falling corner cube reflector whose downward acceleration is measured interferometrically with a stabilized He-Ne laser. This technique for making gravity measurements has been used successfully by several other researchers [Arnautov et al., 1979; Cannizzo et al., 1978; Faller, 1965; Guo et al., 1981; Hammond and Faller, 1967; Hammond and Illif, 1978; Murata, 1978; and Sakuma, 1974]. We have made a considerable effort to minimize the size and complexity of the instrument to facilitate its rapid deployment without sacrificing accuracy. In our recently completed survey, which was the instrument's first trial involving a series of successive measurements at a number of different locations, an accuracy of 10μgal was routinely achieved while the necessary site occupation time was generally less than one day.

2. The Instrument

Figure 3 illustrates the principle of the instrument's operation. A Michelson interferometer determines the position of a corner cube which is allowed to fall freely inside a vacuum chamber. By accurately measuring the arrival times of a subset of interference fringes, the falling object's acceleration is calculated. This provides a measure of the local acceleration

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due to gravity that is tied to the laser wavelength and the frequency of the rubidium standard which is used in the timing electronics.

To minimize nongravitational forces on the falling object, it is surrounded by a servo controlled motor-driven chamber which moves vertically inside the main vacuum system. The dropping chamber effects the release of the falling object and then tracks it (without physically coming into contact with it) during the measurement. As a result, the falling corner cube is shielded from drag due to an imperfect vacuum. The falling chamber also provides an electrically conducting shell surrounding the dropped object so that external electrostatic fields do not affect the measurement. In addition, the purely mechanical character of the release removes the necessity for having any sort of magnetic support or release mechanism that might result in a residual magnetic force during the measurement.

At most sites that were visited, the entire operation of unloading, assembling the instrument, acquiring the data, disassembly, and re-loading required less than one day. The vacuum chamber was pumped continuously, even during transport in a small truck. This provided the pump-down time that would otherwise have been necessary preceding each measurement. At three ~~of the~~ sites, mechanical problems inside the dropping chamber needed attention and as a result the vacuum was lost. This usually meant an overnight delay to obtain a good vacuum after the problem was corrected.

When no such difficulties were encountered, the operation proceeded smoothly and rapidly. After unloading, two half-racks of electronics containing all of the necessary data acquisition and control electronics were interfaced to each other and connected to the mechanical components, which included an interferometer base, a long period isolator [Rinker and Faller, 1981], and an evacuated dropping chamber. These three components required

minimal mechanical alignment. Under normal conditions, the time needed to get the instrument setup and running was two hours. Although gravity data were available immediately following the instrument's assembly, they were generally rejected because of known instrumental biases that can result from temperature transients. To insure quality gravity measurements the instrument had to remain passive for an hour or so after its initial setup and testing. During this time, the laser, the long-period isolator, and the pressure in the vacuum chamber equilibrated with the new temperature environment.

The period over which actual measurements were taken varied among the sites from several hours to as long as one day. Since a data set of 150 drops can be taken in ten minutes, the statistical uncertainty is outweighed by systematic effects after a few hours of measurements. Disassembly and reloading required approximately one hour, as did the transfer of the absolute value from the measurement height to the floor using a relative gravimeter.

3. Results

Table 1 lists the results from the absolute gravity survey. Included in this list are earlier data from two measurements at a site in Denver, Colorado and the original measurements from our lab at JILA. The result from one of the twelve sites, Great Falls, MT, has been omitted. Floor motions at this site, evidenced by analysis of both the long-period isolator signal and time shifts related to the dropped object's position in its fall, as well as other unfavorable characteristics of the surroundings, resulted in a measurement uncertainty that we believe is at least an order of magnitude larger than obtained elsewhere.

The uncertainty stated for each site is a one sigma estimate of the absolute accuracy based on a root-summed-square incorporation of four terms. The first is a 4 μgal uncertainty from instrumental effects which include non-gravitational forces, optical path effects, and timing accuracy. The second term is a 5 μgal uncertainty from possible errors in the laser wavelength. Analysis of the data to date indicates that the laser we used in the March 1982 Denver measurement and the Kresge lab measurement may be the source of a 10 to 20 μgal systematic error. Results from these sites have accordingly been assigned larger uncertainties.

The next term in the uncertainty comes from the transfer done with a relative gravity meter from the effective absolute measurement height of 110 cm to the site floor. This 5 μgal contribution is a pseudo error in cases where the data will be used to look for changes in gravity with time using the same instrument, because subsequent measurements will be done at the same height. It also exaggerates the overall error when comparisons are made with results from other absolute instruments, since the effective measuring heights are usually comparable. Nevertheless, this error term has been included because it is a valid source of uncertainty when the absolute data are used in conjunction with relative gravity surveys whose measurements heretofore have been made at the floor level.

The last term used to calculate the uncertainties in Table 1 is the statistical error based on the random scatter in the measurements at a particular site. The statistical uncertainty or standard error E is calculated from

$$E = \sigma/\sqrt{N-1}$$

where σ is the standard deviation in the results of sets of 150 drops, and N is the number of data sets taken. σ varies among the sites from 4 μgal to 15 μgal and N ranges from 5 to 22.

4. Discussion

It should be noted that uncertainties from instrumental effects are based on the exhaustive search made in our JILA laboratory for systematic errors. The environments encountered at some of the sites were less favorable than that of the laboratory. This was especially true in regards to temperature stability. Temperature transients are known to cause temporary shifts in the measured value of g when the temperature changes are rapid. Our feeling is that an overall uncertainty estimate of around 10 μgal at each of the sites is reasonable. However, only through a continued program of instrumental evaluation, both in the lab and in the field, can this estimate of the accuracy be substantiated.

Only two sites have been visited more than once by the JILA absolute gravity meter: the JILA lab in Boulder and the absolute site in Denver. The two Denver measurements disagree by 20 μgal and are separated in time by only 2.5 months. The disagreement is close to a significant level and is probably due to errors in the particular laser used that have subsequently been identified.

Data gathered over a year's time from our laboratory site provide an indication of the instrument's long-term stability. Figure 4 is a plot of gravity averages in our lab. Over the one year period in which these data were obtained, the apparatus was repeatedly disassembled, modified, and transported (in one case, to another continent and back). The standard deviation of these averages is only 6 μgals. This high degree of repeatability indicates that the problem of drift that is almost always present in relative gravity meters is not present in the absolute meter.

Table 2 compares the results obtained by the JILA instrument with those of the Air Force Geophysics Laboratory (AFGL) and the Istituto di Metrologia

"G. Colonnetti" (IMGC) [Marson and Alasia, 1978, 1980]. All three instruments report typical accuracies of 10 μgal, so most of the intercomparisons between any two instruments should agree within about 14 μgal. This is true at some sites, but not at others. Some of the differences could be due to real gravity changes, because simultaneous measurements have rarely been made. It is more likely, however, that the discrepancies are due to systematic errors that are as yet unrecognized. The results of the AFGL instrument have been biased by some 80 μgal since February of 1981 due to unknown reasons (J. Hammond, personal communication), so the comparisons made with that instrument since that date have been omitted.

Compared with both the IMGC and the AFGL instruments, the JILA instrument is in its infancy. However, the rate with which it can acquire data is sufficiently high that a large number of experiments have already been done with it to detect systematic errors and to date we have found no error sources that could account for the discrepancies seen at some of the sites.

5. Conclusions

Because of its sensitivity to both vertical position and mass distribution, gravity data can provide a powerful and unique contribution to the study of crustal dynamics. In the past, inadequacies in the long-term stability of existing relative gravity meters, and the difficulties involved with transporting and operating absolute gravity meters, have raised questions concerning their usefulness to investigations of tectonic motions. The success of this survey with the JILA absolute gravity meter, however, demonstrates that the accuracy needed to detect small changes in gravity resulting from tectonic motions is now available in an easily portable and durable type of apparatus.

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References

Arnautov, G. P., E. P. Kalish, F. I. Kokoulin, V. P. Koronkevich, A. I. Lokhmatov, I. S. Malyshev, Yu. E. Nesterikhin, L. A. Petrashevich, M. G. Smirnov, Yu. F. Stus', and V. G. Tarasyuk, Measurement of the absolute acceleration due to gravity using a laser ballistic gravimeter, Sov. J. Quantum Electron., 9, 333-337, 1979.

Cannizzo, G., G. Cerutti, and I. Marson, Absolute gravity measurements in Europe, Il Nuovo Cimento, 1C, No. 1, 39-85, 1978.

Faller, J. E., Results of an absolute determination of the acceleration of gravity, J. Geophys. Res., 70, 4035-4038, 1965.

Faller, J. E., R. L. Rinker and M. A. Zumberge, Plans for the development of a portable absolute gravimeter with a few parts in 10 to the 9 accuracy, Tectonophysics, 52, 107-116, 1979.

Guo, Y. G., D. L. Huang, D. X. Li, G. Y. Zhang, J. L. Gao, Y. Y. Fang, and C. Q. Huang, Transportable gravimeter for the absolute determination of gravity, in Proceedings of the Second International Conference on Precision Measurement and Fundamental Constants, NBS, Gaithersburg, Maryland, in press, 1981.

Hammond, J. A., and J. E. Faller, Laser interferometer system for the determination of the acceleration of gravity, IEEE J. Quant. Electron., QE-3, No. 11, 597-602, 1967.

Hammond, J. A., and R. I. Iliff, The AFGL absolute gravity program, in Applications of Geodesy to Geodynamics, Proceedings of the 9th GEOP Conference, Dept. of Geodetic Science Report No. 280, The Ohio State University, Columbus, Ohio, 245-248, 1978.

Honkasalo, T., On the tidal gravity correction, Bollettino di Geofisica Teorica ed Applicata, VI, N. 21, 34-36, 1964.

Marson, I., and F. Alasia, Absolute gravity measurements in the United States of America, Report AFGL-TR-78-0126, prepared for Air Force Geophysics Laboratory, Hanscom AFB, 1978.

Marson, I., and F. Alasia, Absolute gravity measurements in the United States of America, Report AFGL-TR-81-0052, prepared for Air Force Geophysics Laboratory, Hanscom AFB, 1980.

Murata, I., A transportable apparatus for absolute measurement of gravity, Bulletin of the Earthquake Research Institute, 53, 49-130, 1978.

Rinker, R. L., and J. E. Faller, Long period mechanical vibration isolator, in Proceedings of the Second International Conference on Precision Measurement and Fundamental Constants, NBS, Gaithersburg, Maryland, in press, 1981.

Sakuma, A., A permanent station for the absolute determination of gravity approaching one micro-gal accuracy, in Proceedings of the International Symposium on the Earth's Gravitational Field and Secular Variations in Position, Dept. of Geodesy, University of New South Wales, Sydney, 674-684, 1974.

Zumberge, M. A., R. L. Rinker, and J. E. Faller, A portable apparatus for absolute measurements of the earth's gravity, Metrologia, in press, 1982.

Table 1. Gravity values transferred to the floor in gal (cm/sec^2)

Date	Site	Result	Uncertainty (μgal)	Gradient (μgal/cm)
4-10 Apr 81	JILA	979. 608 562	7	2.39
2-4 May 81	JILA	979. 608 569	6	
6-12 Jun 81	JILA	979. 608 566	7	
1-6 Jul 81	JILA	979. 608 573	7	
11-15 Dec 81	JILA	979. 608 569	10	
1-25 Feb 82	JILA	979. 608 557	12	
14-15 Apr 82	JILA	979. 608 573	9	
16-17 Dec 81	Denver	979. 598 322	12	2.92
1 Mar 82	Denver	979. 598 302	12	
21 Mar 82	Holloman AFB	979. 139 615	8	2.99
26 Mar 82	Vandenberg AFB	979. 628 137	9	3.44
27 Mar 82	Lick Observatory	979. 635 503	9	4.42
29 Mar 82	Owens Valley	979. 444 410	8	2.93
1 Apr 82	Kresge Lab	979. 560 457	13	2.65
7 Apr 82	Pinyon Flat	979. 284 081	11	2.88
9 Apr 82	Goldstone	979. 444 216	9	2.47
16 Apr 82	Sheridan	980. 208 952	9	2.58
28-29 Apr 82	NBS, Gaithersburg	980. 103 259	9	3.25
1 May 82	Hanscom AFT, AFGL	980. 378 725	8	3.07

Note: The JILA results differ slightly from previously published values because a more recent gradient measurement has been used in the transfer to the floor.

Table 2

	JILA		AFGL		IMGC	
	1981	1982	1979	1980	1977	1980
Holloman AFB	result (gal) date gradient $g-\bar{g}$ at h=1m	979. 139 615 21 March 2.99 +12	979. 139 600 6 July 2.85 +11	979. 139 600 14&31 May 2.85 +11		979. 139 584 2-3 June 3.14 -34
Vandenberg AFB		979. 628 137 26 March 3.44 -38		979. 628 190 3-4 June 3.21 +38		
Lick Obs.		979. 635 503 27 March 4.42 -13		979. 635 503 6-8 June 4.15 +13		
JILA	979. 608 568 Apr.-Dec. 2.39 +10	979. 608 565 Feb.-Apr. 2.39 +6		979. 608 585 18-23 Oct. 2.28 +38		979. 608 498 26-27 May 2.32 -54
Sheridan		980. 208 952 16 April 2.58 -17	980. 208 912 18-19 July 2.32 -31	980. 208 964 13-16 Oct. 2.44 +9		980. 209 007 12-14 June 2.56 +40
NBS		980. 103 259 28-29 April 3.25 +1		980. 103 257 13-14 March 3.25 -1		
AFGL		980. 378 725 1 May 3.07 +30	980. 378 685 2 yr. ave. 2.97 0	980. 378 685 1 yr. ave. 2.97 0	980. 378 659 Oct.& Dec. 3.02 -30	
Denver	979. 598 322 16-17 Dec. 2.92 +30	979. 598 302 1 Mar. 2.92 +10		979. 598 277 27-29 Apr. 2.92 -15	979. 598 268 16-19 Oct. 2.94 -25	

Each entry consists of the reported floor value in gal without a Honkasalo correction (Honkasalo, 1964), the dat of the measurement, the gradient in microgal per cm used to transfer to the floor from the effective measuring height of the particular instrument, and a comparison term in microgal. The comparison term was calculated by transferring all of the values to the nominal height of 1 meter using the reported gradients, and then differenc each result from the mean of all the adjusted results at that site. This decreases the contribution to the discrepancies from differences in the measured gradients. AFGL's value at JILA is transferred to the common si using -16 microgal.

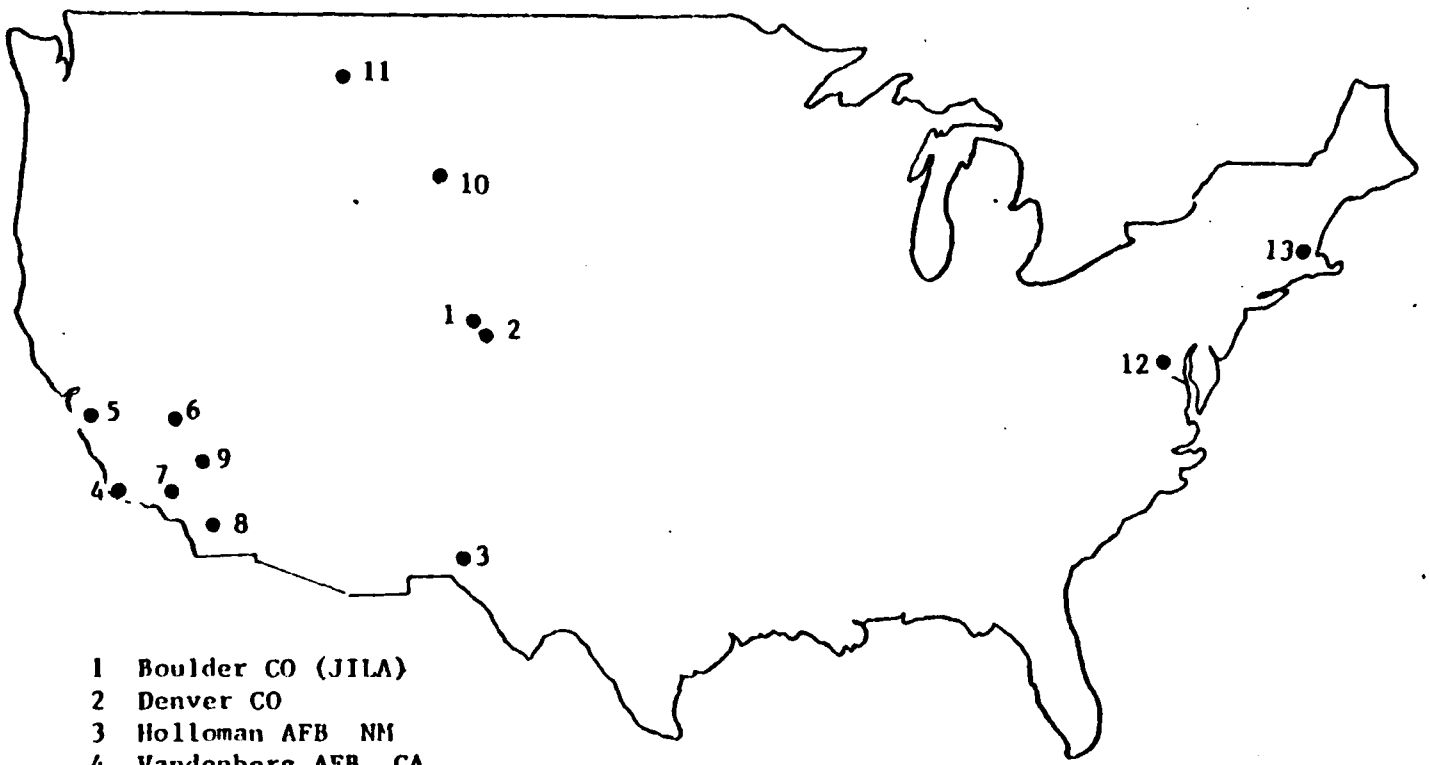
Figure Captions

Fig. 1. Sites of absolute gravity measurements.

Fig. 2. Photograph showing instrument at the Denver site. Normally the large dewar (seen in foreground) is left in the truck.

Fig. 3. Schematic of absolute gravimeter.

Fig. 4. Absolute gravity measurements at JILA over a one-year period. One vertical division is 10 μgal.



1 Boulder CO (JILA)
2 Denver CO
3 Holloman AFB NM
4 Vandenberg AFB CA
5 Lick Observatory CA
6 Owens Valley Observatory CA
7 Pasadena CA (Kresge Lab)
8 Pinyon Flat Observatory CA
9 Goldstone Observatory CA
10 Sheridan WY
11 Great Falls MT
12 Gaithersburg MD (NBS)
13 Hanscom AFB MA (AFGL)

Figure 1

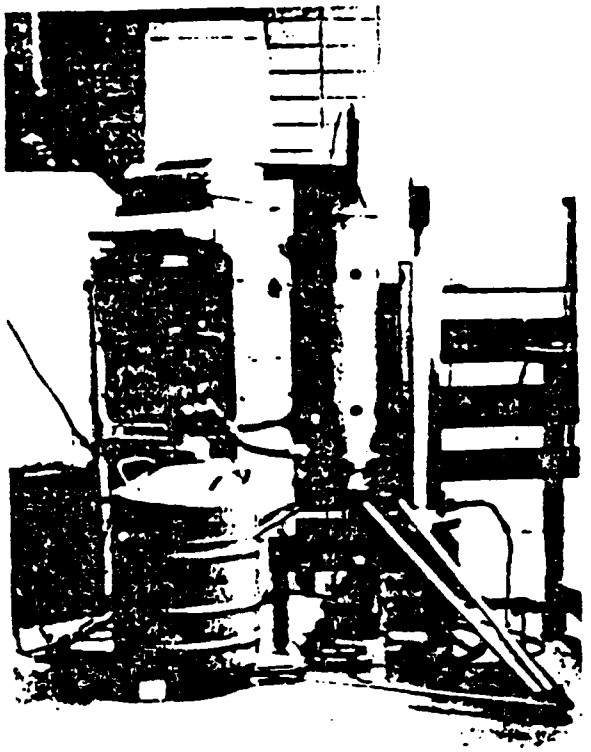
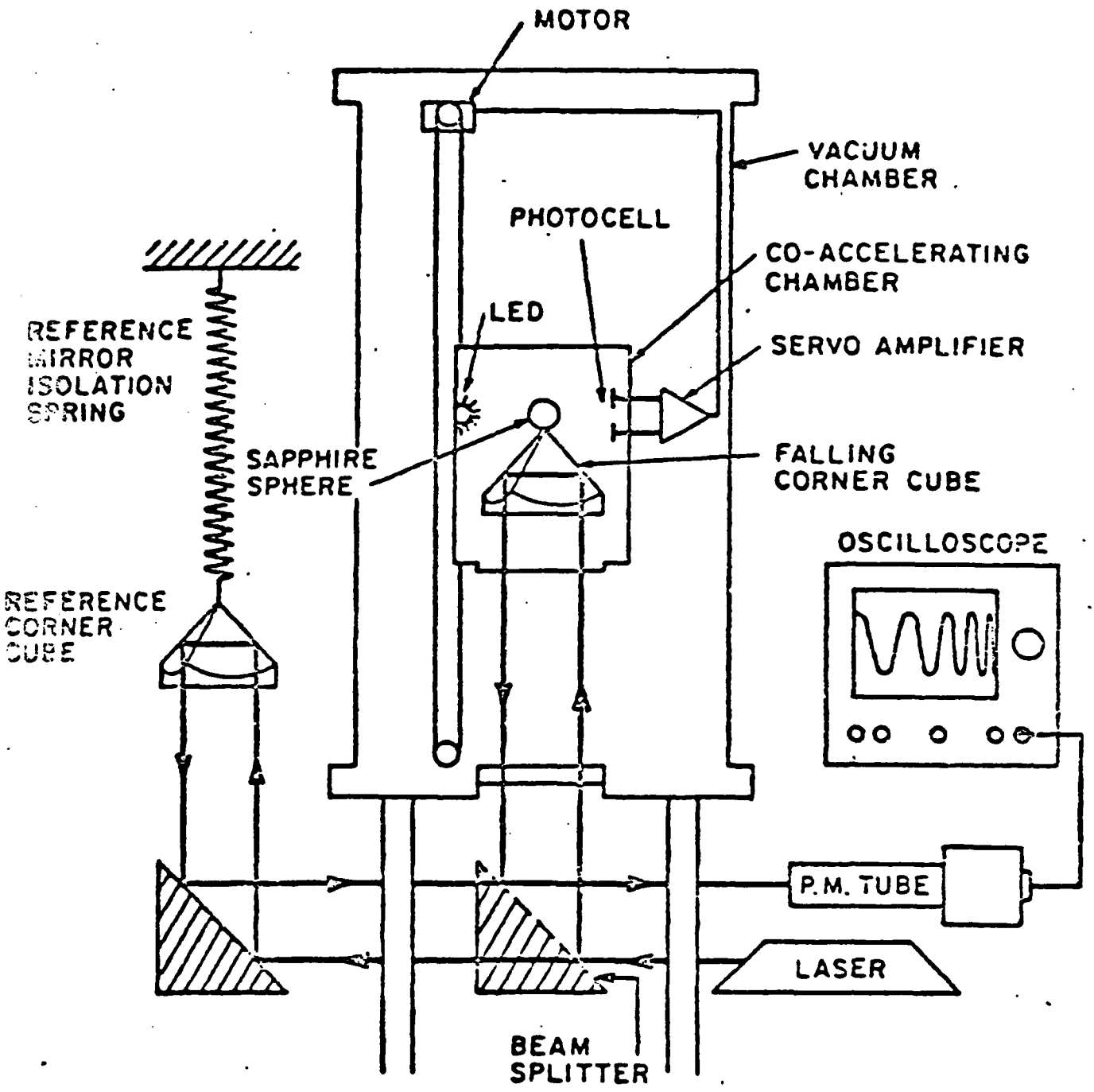


Figure 2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VACUUM CHAMBER
PHOTOCELL
CO-ACCELERATING CHAMBER
LED
SERVO AMPLIFIER
REFERENCE MIRROR ISOLATION SPRING
SAPPHIRE SPHERE
FALLING CORNER CUBE
OSCILLOSCOPE
REFERENCE CORNER CUBE
P.M. TUBE
LASER
BEAM SPLITTER

Figure 3

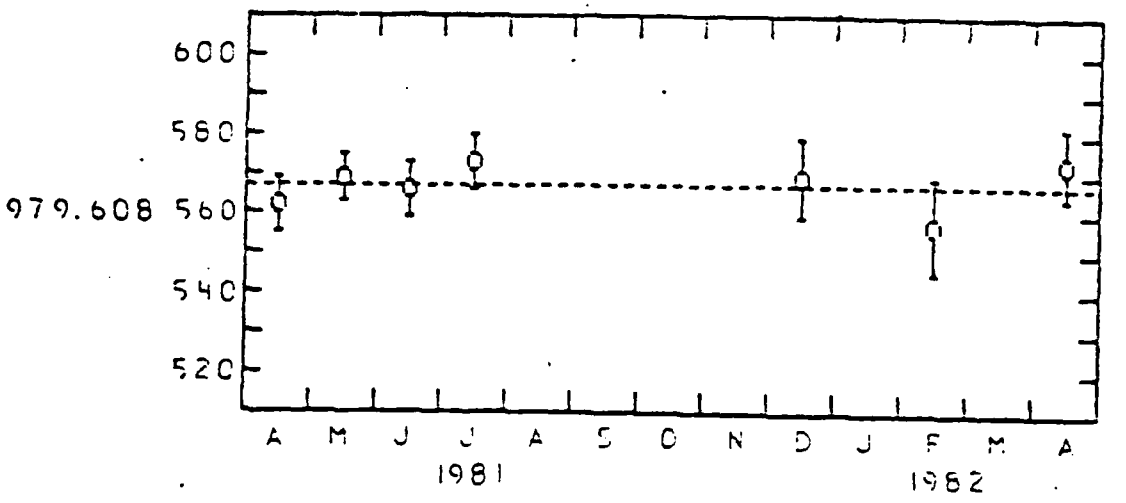

Figure 4